The Fiber

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The term "The Fiber" has become part of our usual language and although in many cases we do not understand very well everything it means, what we do know is everything it provides us. If we were to ask someone who was not related to the telecommunications sector, they would probably tell us that Fiber "is what allows us to have access to all the communication services in our home. From movies and music in streaming, to personal, teaching or business videoconferences, through games, shopping, booking tickets for events, fast internet access and everything that is to come".

Precisely that "everything that is to come" is the most exciting part of this technology and it was what Telefónica anticipated more than fifteen years ago to launch an investment that in those days did not have, far from it, a clear business case.

But before talking about what fiber can bring us in the not-too-distant future, I would like to delve a little deeper into what fiber is, how and when deployments began, why this technology was chosen over others, and how fiber contributes to the development of society in general through the digitization of companies and homes.

1. A bit of history

The reader who is under thirty years old will probably not even recognize what I am going to tell you in the next few paragraphs, but in the 90s, when personal computers began to be a more or less common item in homes and we began to discover the first digital services, such as email and access to browsers to search for all kinds of information in what began to be called the network of "Internet", the way to connect to it was through a dial-up modem.

A dial-up modem is a device, a board inside the computer, or an external box connected to the computer, that plugs into the landline and allows connectivity to another computer, peer-to-peer, or through an Internet Service Provider (ISP) server.

The maximum connection speed of those first modems was 1200 bps (bits per second). That is between half a million and a million times less, approximately, than the speed we have today with fiber optic service. Doing a software update, playing online games or watching a streaming video was absolutely unthinkable with these transmission speeds.

From 1200 bps it went to 2400 bps and progressively, in a short time, it reached 56 Kbps.... A 600Mbps fibre service is ten thousand times faster than a 56Kbps modem.

As network content increased in quantity and size, even a 56K modem was absolutely insufficient. Downloading a page with graphic content or an attachment in an email could take several minutes. At that time, downloading emails after a period of disconnection was a process that could take many minutes, even more than an hour, depending on the size of the attachments and the quality of the copper line to which the modem was connected.

But the telephone modem not only had the problem of speed but, when it was used, the telephone line was busy and you could not receive or make calls. If someone picked up the phone to make a call, the connection was cut off and in many cases the download had to be started again. The solution was to contract a second line for data access, so they proliferated all over the world at that time, as did ISDN lines (two channels of 64Kbbs and one of 16Kbps).

When the ADSL modem emerged in the early 2000s, Telecommunications Service Providers immediately began to replace telephone modems, and even many ISDN lines, with this new type of modem.

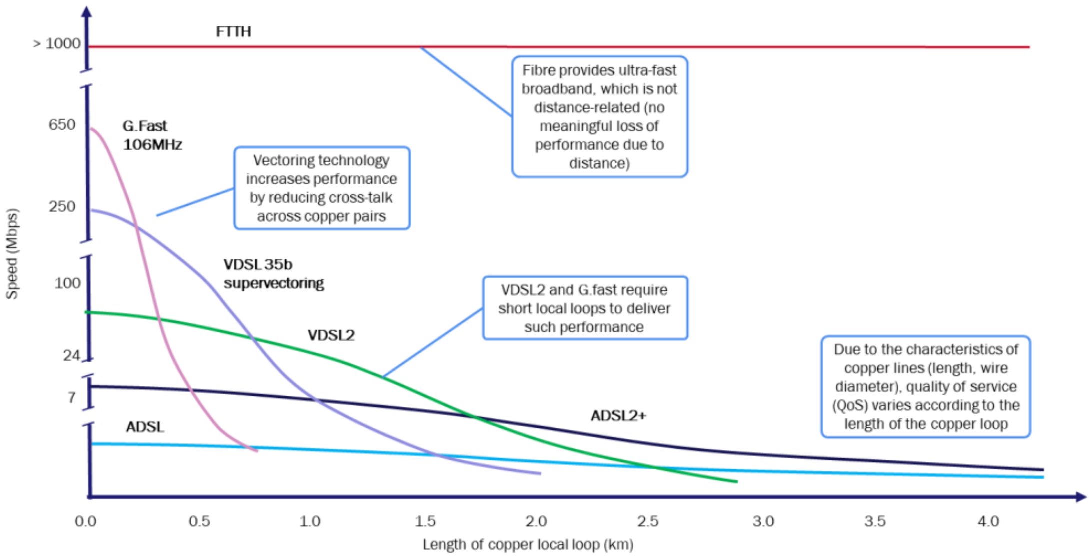
The ADSL modem has two fundamental advantages over telephone modems, it does not block the telephone line to make or receive calls and transmission speeds were around 1Mbps, in the first deployments, and up to 10Mbps when the technology evolved shortly after. It was an impressive advance at that time since the transmission speed and therefore the bandwidth of the service offered was multiplied by 100. Millions of ADSL lines were deployed worldwide in the following five or six years.

The disadvantage of ADSL, the transmission speed decreases very quickly with the distance from the control panel. This meant that the service offered was as technically as possible for potential customers who were located further away from the plant, which meant that a high percentage of the network's potential was wasted.

As always happens with technology, when there is a leap in performance, the services offered on that technology are accelerated. Suddenly you could do things that were absolutely unthinkable with a telephone modem. Attachments could already be several Mega-bytes, information was downloaded from the Internet in a reasonable time, images began to be used on web pages, updates of computer programs began to be "downloaded", instead of installing with a CD, interactive games began to be a reality.... and the first Video services appeared through ADSL, such as Imagenio, today Movistar +, in the case of Telfónica.

But, as is always the case, the new technology soon falls short, the services associated with these broadband deployments with ADSL began to require more and more capacity, for example, with HDTV. The length of the loop began to be a very important limitation, despite the fact that technology continued to evolve and modems with higher transmission speeds were produced as technology advanced, from ADSL to g.Fast, through ADSL2, ADSL2+, VDSL, VDSL2, Vectoring,..... Some of these technologies provide more than 100Mbps, although the distance to the central panel became an increasing limiting factor.

Loop length and downlink capacity, copper broadband technologies [Source: Analysys Mason, 2020]



At this point, in the mid/late 2000s, depending on the country, three options were proposed:

- Shorten the loop. To do this, the solution consisted of "bringing the ADSL/VDSL (DSLAM) equipment closer to the subscriber by reducing the loop to one and a half kilometers or less, by means of an outdoor cabinet installed on the street or in a small building owned by the operator, connected with a point-to-point fiber from the switching center. This solution was implemented in many countries, because it has the obvious advantage of reducing deployment time while accelerating the return on investment, always with the idea of finally reinvesting in Fiber to the home. However, it also has two major drawbacks: power consumption in the cabinet and maintenance of the outside plant.
- Use Coaxial technology. Cable TV operators in the United States, and then in other parts of the world, began to deploy a technology equivalent to ADSL called Cable-modem based on a standard called Docsis. Transmission speeds equivalent to, or higher than, ADSL were achieved, but the drawback is that the number of subscribers per user group was limited so as not to affect performance and that the "upstream" speed (from the subscriber to the exchange) is lower and depending on the services it can become an insurmountable limitation.
- Use a new technology called PON (Passive Optical Network), which consists of replacing the copper loop with Fiber Optics.... Each fiber that leaves the plant branches into a "splitter" (passive optical distributor) from which two, four, eight fibers emerge. With a couple of splitters you can access 16, 32, 64... Subscribers. The first PON technology to be standardized is called GPON, whose capacity is 2.5GBps downstream (to the subscriber) and 1.25Gbps upstream (from the subscriber). As the splitter is a passive element that does not require electrical power, the advantages of saving in operational expenses, OPEX, compared to a copper solution, where a cabinet that requires power has to be placed, are enormous.

A decision had to be made. But first, let's do a little history to better understand the importance of the industrialization of fiber transmission systems and the innovations that led to making it possible.

2. A little bit of technology. Origin of Fiber Optics

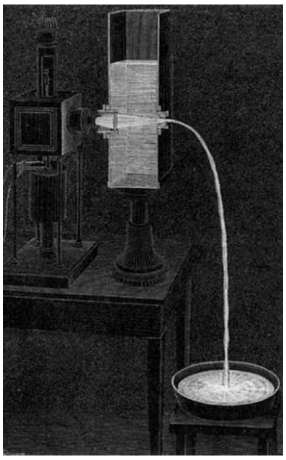
"Theoretical and experimental studies indicate that a glass fiber with a diameter of *λ0* and a coating with a total of 100 *λ0* represents a practical waveguide with significant potential to be a new means of communication. The refractive index of the core has to be about 1% higher than that of the coating. … This waveguide form has an information capacity of more than 1G baud per second. It is completely flexible and supports mechanical tolerances of 10% that can be easily achieved in practice."

These are the words that appear in the conclusions of the article written by K. C. Kao, and G. A. Hockham published in July 1966 and which is considered the origin of the practical use of fiber optics for communications systems.

This study and those that followed, earned K.C. Kao the Nobel Prize in Physics in 2009. This award was shared with Willard S. Boyle and George E. Smith for the invention of the CCD, an invention that opened the door to the digitization of the photos and videos that flood digital communications in the world today. The 2009 Nobel Prize arguably recognizes essential contributions to the new world of telecommunications.

Only four years after the publication of K.C. Kao's work, Corning engineers were able to produce an optical fiber with light-propagating transmission characteristics with 20 dB/km of attenuation as predicted by K.C. Kao.

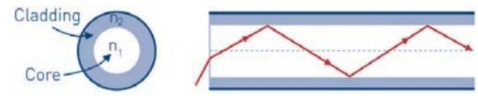
But, to be fair to history, the idea of optical communications by a medium other than air dates back a century before K.C. Kao's article.



In 1842, a hundred years earlier, Daniel Colladon first described what he called a light source or light pipe in his article entitled "On the reflections of a ray of light inside a parabolic liquid current". The paper showed that light propagated following the parabolic path of a flow of water coming out of a reservoir. The enclosed illustration is from a later article, 1884, by Colladon. In the illustration it can be seen that the light perfectly illuminates the jet of water that emanates from an opening made in the tank.

The propagation of light within the water stream is due to the effect of the reflection of light rays caused on the contact surface of two media with different refractive index (water and air in this case). Light is transmitted through a fiber in the same way.

Optical communications in a fiber are based on the reflections of light rays within a silicon fiber wrapped in a covering and whose differences in refractive indices cause most of the light to be reflected in its propagation along the fiber.

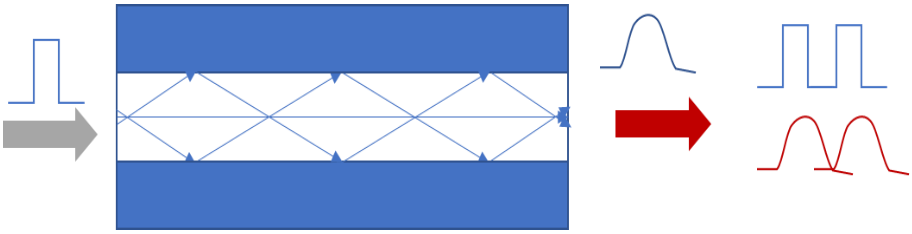


Typical fiber dimensions are 10 to 50 microns for the core and 150 microns including the cover. (The graph shows the beginning. Extracted from the document justifying the Nobel Prize in Physics).

In addition to exposing the transmission capabilities of this optical waveguide, K.C.Kao also detailed the limitations due to material impurities, manufacturing defects and the very nature of the glass fiber material.

There are two key characteristics that define the performance of optical fibers for transmission, 1) efficiency losses due to dispersion and 2) attenuation losses.

Scattering **losses** are due to the widening of the transmitted pulses as the light propagates through the fiber. This widening is caused by differences in the propagation speed of the light components that illuminate the fiber. These components can be either the propagating electromagnetic modes that propagate multimode fibers and singlemode fibers, or the different wavelengths that propagate (chromatic dispersion).

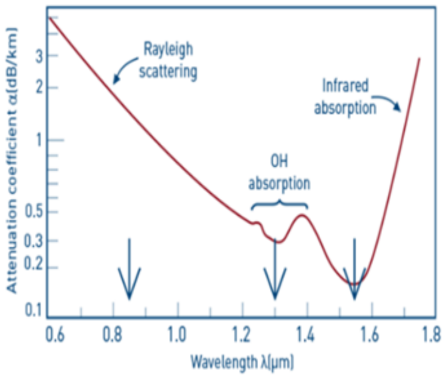


In both cases, the effect is that the pulses transmitted to the fiber input widen and cause the transmission speed to have to be reduced to avoid interference between symbols that increases the level of errors in the received signal.

To eliminate multimodal dispersion, monode fibers, with a much smaller core, are used.

Chromatic scattering can be corrected or limited with appropriate choice of light source that are of higher purity, such as a laser diode instead of an LED diode, with choice of wavelengths where the scattering is non-existent or small, or with the introduction of scattering correction mechanisms.

Attenuation losses in fiber depend on the wavelength of light. The accompanying graph, taken from the document justifying K.C. Kao's Nobel Prize in Physics, shows this variation. Depending on the wavelength, losses are due to different effects intrinsic to the fiber materials.



The wavelengths chosen for on-demand transmission are those that correspond to the least attenuation windows in the d1300 nm and 1550nm environment.

From the 20 dB/km of attenuation that Corning achieved in 1970, attenuations in the range of 0.14 dB/km have now been reached, opening the door to very long-distance communications using fiber optics.

In the access domain, current commercial technology offers speeds of 10Gbps and 25 Gbps at distances between 20 km and 60 km and with plans to offer 50 Gbps and 100 Gbps in 5 years.

3. The big decision

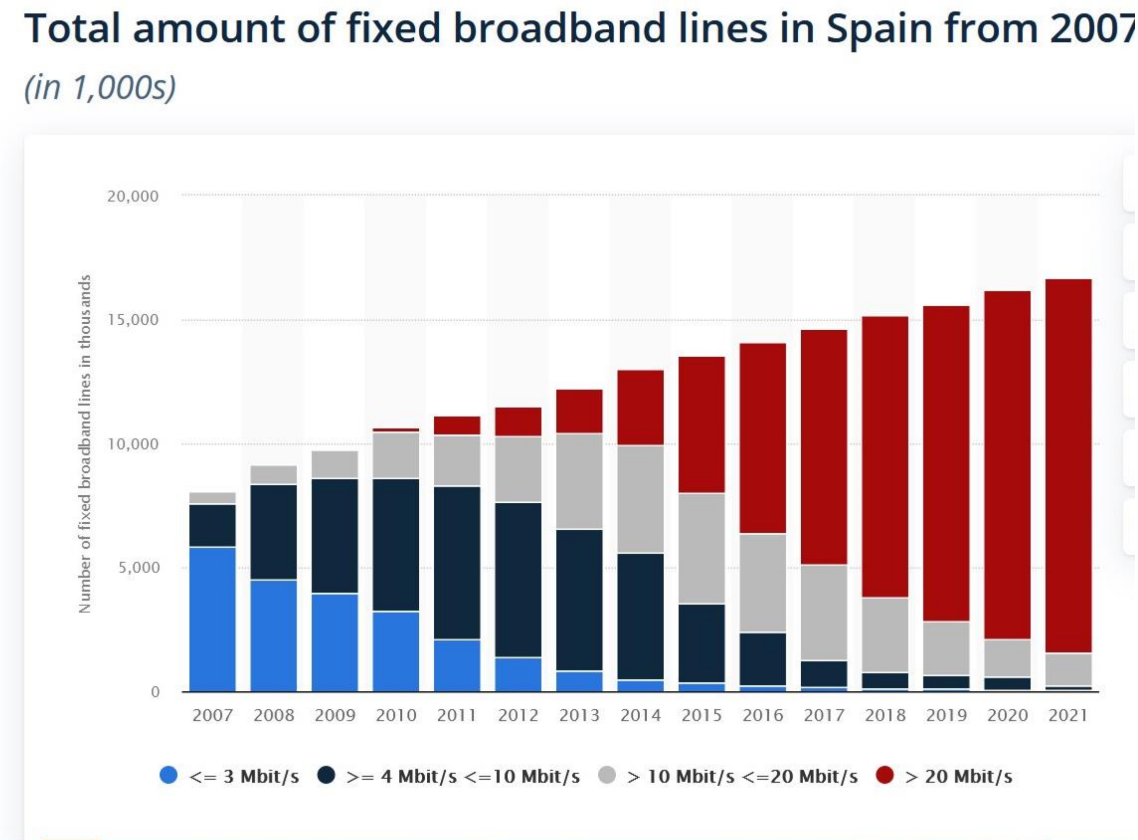
From a purely technological point of view, the decision copper/coaxial or fibre is obvious: Fibre. It is a technology that provides greater bandwidth than either of the other two; that it can offer symmetrical services, essential for services such as videoconferencing; that it can be upgraded in transmission capacity with new versions of the same technology almost to infinity; that contributes to the sustainability and ESG objectives of operators due to the reduction of electricity consumption by one or two orders of magnitude compared to a copper or coaxial network and that, once installed, ultimately protects the investment made over many years.

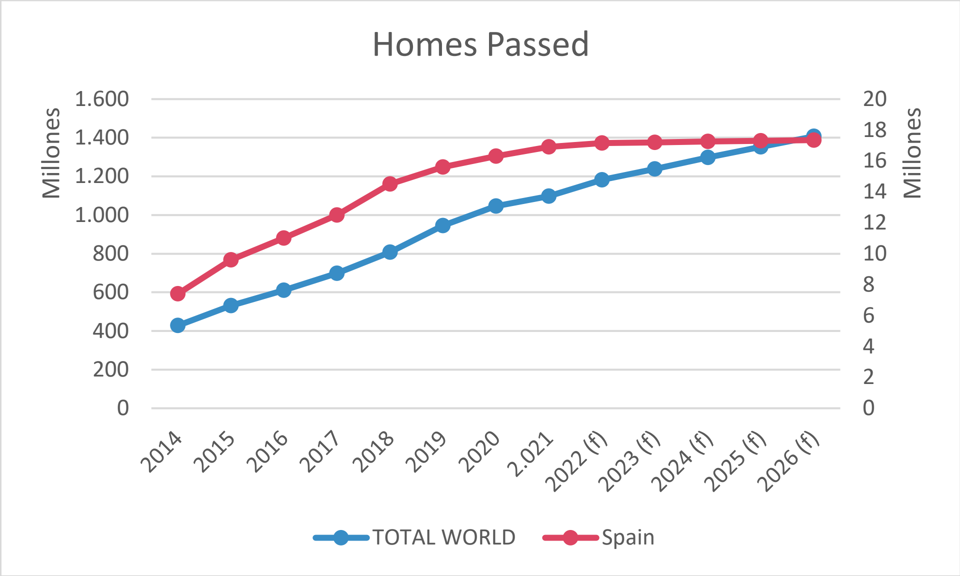
But from an economic point of view it is not so clear, at least in the short term. A fiber deployment requires replacing all the copper, and civil works are expensive and complex, so it requires a lot of capital and time before the investment begins to be recovered at a reasonable pace. The cost per user skyrockets and the amortization times can be up to seven years, or longer. In addition, to be commercially successful, it is necessary to have a sufficiently wide coverage in a very short time, so that users who request the service can be attended to in a reasonable time. All operators were aware that the ultimate goal was Fibre to the Home (FTTH), but many decided to do it in two steps: first bring the fibre closer to about 0.5-1 km from the subscriber and then replace the last sections of copper with Fibre. The cash flow and investment required initially was much lower, but the advantages of having a network capable of supporting any service required by the market would not be palpable until all copper was replaced by Fiber.

Telefónica, in a visionary decision at the time, decided to bet on FTTH around 2007, and it was not the first operator in the world to do so, but it was one of the first and possibly the first in Europe to make the decision and start with deployments of a considerable volume.

That decision, risky at the time, was later proven to be the right one and became especially evident in 2020, when due to the pandemic practically everyone had to live months locked up at home, teleworking. What would have become of the world economy if it had not been for the fact that operators such as Telefónica, years earlier, decided to invest and create an FTTH network that would cover the communication needs of most households? Apart from the economic dimension, it is important not to underestimate the tremendous social impact that a good fibre network had during the days of confinement, providing teleworking tools, but also entertainment and communication, by video, which were undoubtedly of great help to cope with those difficult times. Thanks to that decision, and the fact that other operators had to imitate Telefónica in order to compete, J.M. Álvarez Pallete (CEO of Telefónica) in 2020 was able to say: "Spain has more FTTH lines than Germany, Italy, France and the UK combined".

As can be seen in the following two graphs, the deployment of fibre in Spain is today the subject of a case study due to its effectiveness. The country went from 0% FTTH coverage in 2009 to 85% in 2019, the second-highest fibre penetration in Europe after Portugal. During that period, the bandwidth offered to end customers grew exponentially and almost universal coverage was reached in ten years, well above the average compared to other countries.





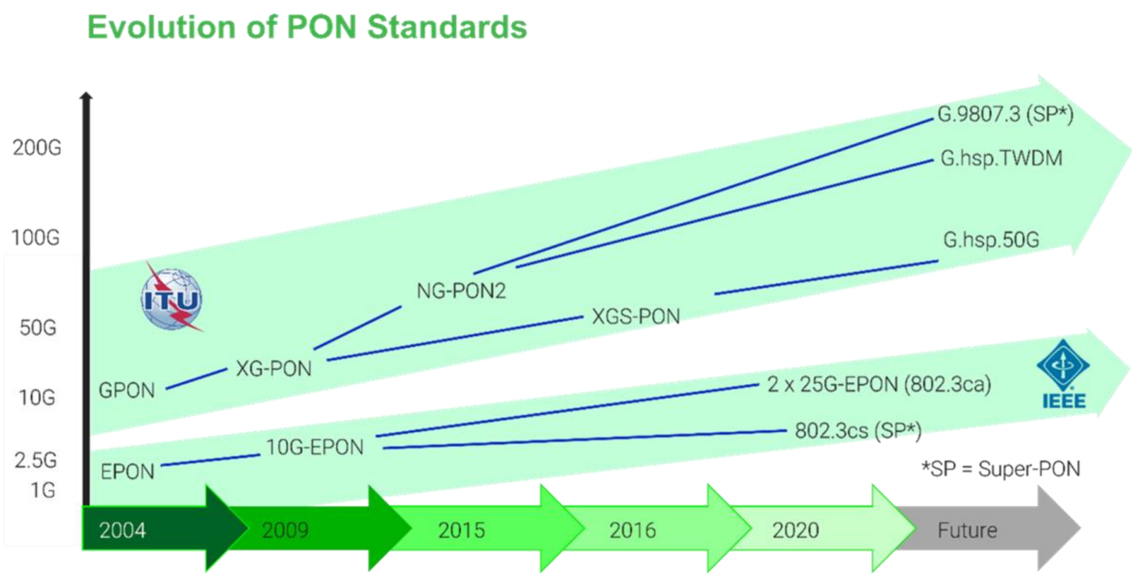
During the COVID19 pandemic, operators around the world who had not yet decided to deploy FTTH and were still offering Broadband service with Copper or Coaxial cable, began to invest in FTTH as quickly as their financial statements would allow. There was no longer any doubt. In order to compete in the market, it was necessary to have a good fibre network complemented by a good 5G/4G network to cover mobility services. Fibre and mobile (5G) do not compete with each other, they complement each other, and the most successful operators around the world are those that, like Telefónica, "merged" both into a competitive commercial offer, complemented by the offer of content and other services.

4. The future

What else can La Fibra offer in the future? The good news is that the possibilities offered by this technology are practically endless. Once the investment has been made in the passive network, fiber and splitters, and there is close to 100% coverage of homes, the technology will continue to evolve, allowing network upgrades to increase bandwidth and reduce latency as services require it.

Currently, most FTTH networks use GPON (2.5Gbps downstream / 1.25 GBps upstream), but it has already reached the point where more new XGS-PON lines (10Gbps/10Gbps) are installed in the world than GPON lines. On the same fiber already installed! 25GPON technology is already beginning to be deployed in some countries and in a few years it will go to 50GPON or even 100GPON, technologies that have already been tested in pilot tests.

As can be seen in the figure below, the standardization bodies, ITU and IEEE maintain a continuous effort to continue increasing the speed that fiber can offer in access to homes, and by extension to companies, and for the connection of base stations, including future ones that are deployed following 6G standard. That's one of the biggest advantages of fiber: Once installed, there are no nearby technological barriers that prevent us from thinking about even higher speeds. As I said in the first lines, fiber will withstand what is to come.



I would like to conclude with a reflection on what the future holds. In recent times there has been a lot of talk about the Metaverse. No one really knows today what the Metaverse will ultimately be, or rather, which applications of the Metaverse will succeed in the first place and in which sectors. Virtual reality, augmented reality, fusion of physical and virtual world with Digital-Twin, ... they can have an infinite number of practical use cases in industry, business, entertainment, health, education,.... In a sense, we are living today in a situation similar to the one we experienced at the end of the 90s, when people began to talk about the Internet, and no one could even imagine what it would really be like later. In the end, it does not matter what exactly the Metaverse will be, because that will depend on the commercial success of each of the applications over time, but what is clear is that it will only be possible with high-performance Fiber networks (and 5G, 6G and whatever is to come) that are capable of providing the bandwidth, the latency needed to make those applications feasible and economically viable. In my opinion, the Metaverse will materialize sooner in those countries whose networks provide the necessary capabilities and coverage, so Telefónica is in a privileged position to be a pioneer once again.

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